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POSSIBILITY OF APPLYING A BIOCOMPOSITE BASED ON WOOD SAWDUST AS A THERMAL INSULATION MATERIAL

***Summary**: A strong relationship exists between renewable energy sources (wind, solar, hydro, geothermal, and biomass) and weather conditions that affect their capacity. Furthermore, climate change alters energy supply and demand patterns, affecting buildings insulation needs directly. All this represents an opportunity for the development of new biomass-based materials to reduce energy consumption and protect the environment. The goal of this research is the application of wood sawdust as an aggregate to obtain a new thermal insulation material and to improve the energy efficiency of buildings.*
***Keywords:** Biocomposite; Thermal conduction; Thermal insulator; Energy efficiency.*

MOGUĆNOST PRIMENE BIOKOMPOZITA NA BAZI DRVNE PILJEVINE KAO TERMOIZOLACIONOG MATERIJALA

***Rezime:** Postoji snažna povezanost između izvora obnovljive energije (vetar, solarna energija, hidroenergija, geotermalna energija i biomasa) i vremenskih uslova koji utiču na njihov kapacitet. Štaviše, klimatske promene menjaju obrasce snabdevanja energijom i potrošnje, što direktno utiče na potrebe za izolacijom zgrada. Sve ovo predstavlja priliku za razvoj novih materijala na bazi biomase koji mogu smanjiti potrošnju energije i zaštititi životnu sredinu. Cilj ovog istraživanja je primena drvne piljevine kao agregata za dobijanje novog materijala za termoizolaciju i poboljšanje energetske efikasnosti zgrada.*
***Ključne reči:** Biokompozit; Toplotna provodljivost; Toplotni izolator; Energetska efikasnost..*

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1. INTRODUCTION

The use of renewable raw materials is one of the key aspects of environmentally friendly construction [13], and one example is that renewable raw materials can be used in the production of thermal insulation materials (TI). In addition to technical and technological requirements, such TI materials also meet economic requirements. The use of TI materials in the outer envelope of the building has a very significant role in increasing the energy efficiency (EE) of the building. The most frequently used materials for this purpose are synthetic, which have a certain number of disadvantages. For example, TI materials based on polyurethane and polystyrene can't be decomposed after use. Also, different synthetic binders and gases that create greater porosity of the material are used, while consuming a large amount of heat and electricity in the production process.

2. THERMAL INSULATION MATERIALS IN CONSTRUCTION

Thermal insulation materials in construction have the task of slowing down the transfer of thermal energy through the outer shell of the building and preventing the occurrence of moisture in the walls, i.e. on certain layers of the wall assembly during the winter period [9][22]. The coefficient of thermal conductivity (λ) defines how a material behaves in terms of thermal insulation capabilities. According to this coefficient, thermal insulation materials can be divided into two groups: first, where $\lambda < 0.06$ W/mK, and the second, where λ is between 0.06 - 0.3 W/mK [19]. Conventional synthetic materials with good thermal conductivity properties (0.025 to 0.048 W/mK) are commonly used as insulation. These materials are very long-lasting, and they are easily incorporated into building elements. In addition, they have disadvantages, such as non-sustainable raw material sources, excessive energy consumption, and the use of dangerous chemicals during production. Certain materials have reduced durability with an increase in temperature, and some are even toxic [22]. In the civil industry, the most frequently applied TI materials are (Figure 1):

1. Expanded and extruded polystyrene (EPS and XPS)
2. Polyurethane (PU)
3. Mineral wool (rock wool and glass wool).

All three types of materials have a high porosity of over 90%. EPS, XPS, and PU are characterised by the dominant closed porosity, water resistance and the impossibility of biological degradation. In contrast to them, stone and glass wool absorb water, but they are not combustible materials as previously mentioned. The common feature of all three types of TI materials is that when they are exposed to high temperatures, they release toxic gases and sooty smoke, which harms human health and the environment. They are mainly applied as the TI of the outer shell of the object [19][22].

On the other hand, by using biodegradable waste materials, which do not require technologies with high energy consumption, the principle of sustainable development is introduced. The use of biomass, primarily wood waste, meets the criteria of sustainable development, reduces pollution and the amount of material that is disposed of in landfills or used for burning.

Figure 1. Synthetic TI materials [9]

There are boards made of reed, cork, wool, baled straw, wood fibers (sawdust), as examples of less frequently used but also less environmentally harmful materials, shown in Figure 2. The coefficient of thermal conductivity of these materials is higher than conventional, and they are in the range from 0.037 to 0.145 W/mK. Due to the poor knowledge about this type of material as thermal insulation, they are rarely used in practice. However, scientific research is increasingly contributing to the application of these TI materials because they have numerous advantages, such as the renewability of the natural resources from which they originate, and at the end of their lifetime, they are biologically degradable. Also, they are not harmful to the environment and human health, and simpler and less energy-demanding production processes produce them. Research and development in science are increasingly producing materials whose components are natural materials, and they are called biocomposite materials. Biocomposites are a mixture of at least two materials that consist of components of natural origin - biodegradable fibers that have the role of reinforcement (aggregate) and binders [1][5][8]. The current research on these materials indicates that their application is possible and widespread. Studying the process of heat transfer through biocomposites is of great importance for determining the thermal properties of this type of material, the knowledge of which is important due to its application as an insulating material [2][14][15][17][20][22]. Curto et al. [7] studied the thermal and acoustic characteristics of materials obtained by mixing natural lime, water and hemp. Their research was conducted on precisely defined sizes and shapes of material samples. The obtained results were compared with the results of other authors, where it was concluded that the new material made of lime and hemp can replace the conventional materials that have been used for a long time. Ninikas et al. [16] studied a type of insulation made from hemp and pine tree bark. Four types of mixtures were made using fibers of the material that were joined with methyl cellulose glue. The difference was reflected in the ratio of tree bark and hemp fibers, which were mixed in the following ratio: 90:10, 80:20, 70:30 and 60:40. The results showed that with an increase in the hemp content, the mechanical properties are improved. However, at the same time, the thermal conductivity coefficient also increases, which represents the negative side of this mixture. Khoukhi [12] and coworkers developed an environmentally friendly thermal insulation material based on short and long-grain rice. Tests have determined the optimal thermal conductivity of this bio-insulating material. Iqbal Cetiner and Andrew D. Shea [6] examined the possibility of using sawdust as a filler for prefabricated walls, which can be used to replace classic concrete walls with conventional TI materials. Christer Tashana Danne M. Gamiao et al. [21] based their research on the production of wooden panels from sawdust as thermal insulation of ceilings in buildings.

Figure 2. Biocomposites based on wood biomass [10]

3. ENERGY EFFICIENCY AND OVERALL HEAT TRANSFER COEFFICIENT

To meet the requirements of EE buildings, the Rulebook is applied, which prescribes the energy properties and the method of calculating the thermal properties of high-rise buildings, as well as the energy requirements for new and existing buildings. The energy efficiency of buildings has been achieved if the following properties are met [18]:

1) Provided minimum conditions,

2) Energy consumption for heating, cooling, preparation of hot sanitary water, ventilation and lighting of the building does not exceed the allowed maximum values per m^2, which are precisely defined according to the Rulebook.

Fulfilling the requirements for EE facilities also includes checking the diffusion of water vapour, which is calculated for external building structures and structures bordering unheated rooms (except rooms bordering the field). All construction structures of the building must be designed and built in such a way that water vapour does not condense on their surfaces. In case of condensation, the drying period is calculated.

In this paper, on the example of 2 walls assembly, the overall heat transfer coefficient is calculated using the URSA software package. As an insulation material for both wall assemblies, a panel made of biocomposite P is used. Biocomposite (P) panels are made from natural aggregate - sawdust procured as waste from the wood industry. Granules of expanded polystyrene (EPS) and lime-gypsum paste in a 4:1 ratio were added to the mixture as a binding agent. The use of EPS aims to enhance the thermal characteristics of the biocomposite P. The volume fractions of the materials in biocomposite P are presented in Table 1, while the component materials are depicted in Figure 3.

	sawdust	granules of expanded polystyrene (EPS)	lime-gypsum paste
Biocomposite P	53,5%	13,5%	33%

Table 1. Volume shares of component materials

a) sawdust b) polystyrene granules c) lime and gypsum

Figure 3. Component materials of biocomposite P

The average distribution of sawdust particles in the aggregate used for the production of the new biocomposite is shown in Table 2.

Biocomposite/ size (mm)	**< 0,4**	**0,4-0,5**	**0,5-1**	**1-2**	**2-4**	**4-8**	**> 8**
Sawdust (%)	22,5	6,8	48,3	8,1	12,2	2,1	0

Table 2. Average distribution of particles in the aggregate

Table 2 shows that the dominant particles are 0.5-1 mm (~48 %), followed by particles smaller than 0.4 mm (22.5 %). The size of the EPS granules is 0.3 cm.

Through preliminary testing on samples with the same composition, the coefficient of thermal conductivity for biocomposite P is calculated and used in this paper [4]. To check EE for two wall assemblies, the overall heat transfer coefficient was determined using the following equation [18]:

$$U = \frac{1}{R_{si} + \sum_m \frac{d_m}{\lambda_m} + R_{se}}$$

where R_{si} and R_{se} are the individual convective heat transfer coefficients for the inner and outer wall sides, λ_m is the coefficient of thermal conductivity, and d_m is the thickness of the m-th layer of the wall.

4. RESULTS AND DISCUSSION

The overall heat transfer coefficient ″U″ was determined for two wall assemblies, the one with a ceramic block and the second with a concrete sheet as a main structure layer, where the thermal insulation material in both cases is the plate made of biocomposite P. Also, the water vapour diffusion resistance factor is calculated for both cases.

4.1. Wall assembly 1 - TI biocomposite P/ceramic block

The characteristics of the wall assembly with TI panel made of biocomposite P, with a thickness of 50 mm and ceramic block as the basic material, are given in Table 3. The coefficient of thermal conductivity and water vapour diffusion resistance factors for all other layers except for biocomposite P are taken from the Rulebook. For biocomposite P, a thermal conductivity coefficient is 0,141 W/mK [4] and the water vapour resistance factor is determined using the dry cup test presented in the doctoral dissertation [3].

	Layers	d (m)	λ (W/mK)	μ	R (W/m²K)
	i				0,125
1	Extension plaster	0,02	0,85	15	0,024
2a	Ceramic block	0,19	0,61	6	0,311
2b	Cement–lime plaster	0,19	0,87	15	0,218
3	TI biocomposite P	0,05	0,141	5,1	0,355
4	External finishing plaster	0,03	0,87	15	0,034
	e				0,04

Table 3: Wall assembly with TI biocomposite P and ceramic block as base material

Based on values shown in Table 3, the value of the overall heat transfer coefficient ″U″ for assembly 1 is

$$\mathbf{U= 1{,}138\ W/m^2K}$$

If EPS of the same thickness is used instead of biocomposite as a thermal insulation layer, this coefficient would be 0.572 W/m^{2}K, and if rock wool of the same thickness is used, this coefficient would be 0.490 W/m^{2}K. Based on the previous, it can be concluded that the overall heat transfer coefficient of a wall made of ceramic block and biocomposite P as a thermal insulation material is about two times higher than assemblies with EPS and rock wool. More precisely, it would mean that such an assembly is twice as bad in terms of thermal insulation compared to walls with EPS and rock wool. To achieve the specified values of the overall heat transfer coefficient with biocomposite P as TI, the thicknesses must be 0.17 m compared to EPS and 0.21 m compared to rock wool.

4.1.1. The water vapour diffusion resistance factor calculation

The values of the water vapour diffusion resistance factor are shown in the following Table 4:

	Leyers	d (m)	λ (W/m K)	μ	R (W/m²K)	r (m)	t (°C)	p'(kPa)	p(kPa)
	i				0,125		20,00 15,12	2,337 1,716	1,285 1,285
1	Extension plaster	0,02	0,85	15	0,024	0,30	15,12 14,20	1,716 1,618	1,285 1,127
2	**Ceramic block**	0,19	0,61	6	0,311	1,14	14,20 2,05	1,618 0,710	1,127 0,525
3	**TI biocomposite P**	0,05	0,141	5,1	0,355	0,26	2,05 -11,79	0,710 **0,221**	0,525 **0,390**
4	External finishing plaster	0,03	0,87	15	0,034	0,45	-11,79 -13,14	**0,221** 0,196	**0,390** 0,152
	e				0,04		-13,14 -14,70	0,196 0,169	0,152 0,152

Table 4. The water vapour diffusion resistance factor for assembly 1 with the ceramic block

The conditions for the calculation of water vapour diffusion resistance factor are as follows: t_i=-14,7°C, φ_i=55%, φ_e=90%, where t_i represents a projected air temperature in winter conditions for the city of Kraljevo, φ_i represents the inner, and φ_e the outer relative humidity of air.

Based on values shown in Table 4, it can be seen that condensation occurs between the 3rd and 4th layer (p>p′), and it will dry out in 23 days, which is allowed values provided by the Rulebook.

4.2. Wall assembly 2 - TI biocomposite P/ concrete panel

The characteristics of the wall assembly 2 with TI biocomposite P, thickness 50 mm and concrete panel as the basic material are given in Table 5. The coefficient of thermal conductivity and water vapour diffusion resistance factors for all other layers except for biocomposite P are taken in the same way as for wall assembly 2.

	Leyers	d (m)	λ (W/mK)	μ	R (W/m^2K)
	i				0,125
1	Extension plaster	0,02	0,85	15	0,024
2	**Concrete panel**	0,1	2,04	60	0,049
3	**TI biocomposite P**	0,05	0,141	5,1	0,355
4	External finishing plaster	0,03	0,87	15	0,034
	e				0,04

Table 5. Wall assembly 2 with TI biocomposite P and concrete panel as the basic material

Based on values shown in Table 5, the value of the overall heat transfer coefficient ″U″ for assembly 2 is:

U= 1,596 W/m^2K

If EPS of the same thickness is used instead of biocomposite as a thermal insulation layer, this coefficient would be 0.670 W/m^2K, and if rock wool of the same thickness is used, this coefficient would be 0.559 W/m^2K. Based on the previous, it can be concluded that the overall heat transfer coefficient of a wall made of a concrete panel and bicomposite P as a thermal insulation material is about two times higher than assemblies with EPS and rock wool. To achieve the specified values of the overall heat transfer coefficient with biocomposite P as TI, the thicknesses must be 0.17 m in the case of EPS and 0.21 m compared to rock wool.

4.2.1. The water vapour diffusion resistance factor calculation

The values of the water vapour diffusion resistance factor are shown in the following Table 6:

	Leyers	d (m)	λ (W/mK)	μ	R (W/m^2K)	r (m)	t(°C)	p'(kPa)	p(kPa)
	i				0,125		20,00 13,08	2,337 1,506	1,285 1,285
1	Extension plaster	0,02	0,85	15	0,024	0,30	13,08 11,78	1,506 1,384	1,285 1,237
2	**Concrete panel**	0,1	2,04	60	0,049	6,00	11,78 9,06	1,384 1,156	1,237 0,266
3	**TI biocomposite P**	0,05	0,141	5,1	0,355	0,26	9,06 -10,58	1,156 0,245	0,266 0,225
4	External finishing plaster	0,03	0,87	15	0,034	0,45	-10,58 -12,49	0,245 0,207	0,225 0,152
	e				0,04		-12,49 -14,70	0,207 0,169	0,152 0,152

Table 6. The water vapour diffusion resistance factor for assembly 2 with a concrete panel

It can be seen from the above table that there is no condensation in this assembly.

5. CONCLUSION

In the final analysis of the obtained values presented in the tables, it can be noted that in assembly 1, which uses ceramic block as the basic material, condensation occurs between the 3rd and 4th layers. In the case of assembly 2, which uses a concrete panel as the basic material, no condensation is observed. However, despite the absence of condensation in assembly 2 with the concrete panel, it was found to perform worse in terms of the overall heat transfer coefficient U, calculated by EE. When comparing walls with biocomposite P as an insulating layer, it can be concluded that the tested wall assemblies are twice as ineffective as walls built with EPS and rock wool. To achieve the same energy efficiency, the thickness of the biocomposite P as the insulation layer must be greater. Nevertheless, this method of insulating buildings using a biocomposite is far superior in terms of protecting the living environment, reducing energy consumption during production processes, minimizing CO_2 emissions, and positively impacting human health. These are important factors in the selection of TI materials.

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